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MINIMUM NONPROPAGATION CRITERIA FOR LOAD, ASSEMBLE, AND PACK (LAP) FACILITIES FOR THE BLU-97/B SUBMUNITION

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This program was accomplished as part of the U.S. Army's Manufacturing Methods and Technology program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in the production of Army materiel. Test coordination and basic data reduction (cont)

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As part of an Army-wide expansion and modernization program, the safe-separation distance for production of BLU-97/B submunitions was studied and determined in a series of tests. The results were used to establish safety criteria for new load, assemble, and pack (LAP) facilities and also existing facilities under renovation. The program to determine the necessary minimum nonpropagation distance was conducted in four phases:

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18. SUPPLEMENTARY NOTES (cont)

were accomplished by the ARDC Resident Operations Officer, National Space Technology Laboratories, NSTL Station, Mississippi. Both exploratory and confirmatory tests were conducted by the Hazard Range Support Unit of Computer Science Corporation of NSTL.

20. ABSTRACT (cont)

Phase 1. Pallets of 16 submunitions separated by a barrier allowing air-flow. A distance of 1.54 m (5.0 ft) was established.

Phase 2. Pallets of 16 submunitions separated by a solid barrier. A distance of 1.33 m (4.0 ft) was established.

Phase 3. Single submunitions separated by a 9.5 cm (3.75 in.) high barrier. A distance of 22.9 cm (9.0 in.) was established.

Phase 4. Single submunitions separated by a full height barrier. A distance of 22.9 cm (9.0 in.) was established.

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INTRODUCTION

At present, an Army-wide modernization program is underway to upgrade existing facilities and develop new ones for explosive manufacturing and load, assemble, and pack (LAP) operations. This continuous program will enable the Army to increase production cost effectiveness and improve functional safety. It will also provide manufacturing capability for future weapon systems within the existing facilities at currently operational Army Ammunition plants (AAPs). As an integral part of this program, the Armament Research and Development Center provides support in the area of safety engineering which includes safe separation distance studies to prevent propagation of unplanned detonations involving end items, explosive subcomponents, and inprocess bulk explosive materials.

Although this report covers safety criteria developed for the LAP facility for BLU-97/B submunitions at the Kansas Army Ammunition Plant (KAAP), these criteria will be used in the design of all explosive installations due for modernization and will be available for reference purposes to privately owned, privately operated (POPO) plants engaged in ordnance related manufacturing.

Specifically, the test program at KAAP was implemented to determine the safe spacing distance for various BLU-97/B submunition LAP facilities under simulated loading plant conditions so that the effects of a major accidental detonation during manufacture would be limited to the immediate area or loading bay and would not be propagated to the adjacent loading activities with catastrophic results. Therefore, the only acceptable criterion for the establishment of safe separation distances is the nonpropagation of the detonated submunition (donor) to the impacted submunitions (acceptor). These separation distances were measured in two ways: (1) edge to edge from the bodies of the nearest submunitions between pallets containing 16 submunitions and (2) centerline to centerline on the individual submunitions.

TEST CONFIGURATION

General

The presently planned production facility process flow diagram, from empty metal parts and bulk explosives, through the BLU-97/B submunition loading operations, to the loading of the submunitions into their SUU-65/B dispensers and the final transfer of the packaged dispensers to storage areas is shown in figure 1. After a review of this flow diagram, a test plan consisting of two test phases was configured and mutually agreed upon. The two phases, each representative of a different LAP line configuration, are loading pallets containing 16 submunitions and single submunitions.

Testing was conducted by the ARDC Resident Operations Office at the National Space Technology Laboratories' (NSTL) Hazards Test Range facility located in Mississippi.

Test Specimen

The basic test specimen was an unfuzed BLU-97/B submunition (fig. 2). The LAP line arrays were configured, either single submunition or pallets containing 16 submunitions (fig. 3) each, depending on the portion of the assembly line being simulated.

The BLU-97/B submunition is aircraft dispensed (202 units per SUU-65/B dispenser) with antimateriel, antipersonnel, antitank, and incendiary capabilities. The major elements of the submunition assembly are a two piece, controlled fragmentation, welded steel body; a copper shaped charge liner; a fuze assembly; a zirconium ring for incendiary capabilities; an inflatable decelerator for air orientation; and a standoff tube as the fuze's primary firing circuit. The submunitions body contains 317.5 g (0.7 lb) of cyclotol (70% RDX/30% TNT), with its nose cavity machined out to accept the fuze base, booster assembly, and zirconium incendiary ring.

For this program, the fuze train and zirconium ring were omitted from the test specimen arrays because the out-of-line safety mechanism's ability to interrupt unplanned explosive train functioning has already been validated. Also, since the objective of this program is the prevention of the propagation of detonations, the zirconium incendiary ring was also omitted.

On the tests using pallets of 16 submunitions (fig. 3), the stainless steel pouring funnels were omitted due to their scarcity; however, barriers found to be necessary during testing were constructed with enough height to fully shield the pallet and four quadriholed pouring funnels. Also, in the interest of cost savings, the cast aluminum pallets (base plate and holders) were replaced by wooden components (fig. 4). This is considered a valid substitution since the wooden acceptor pallets offered less resistance to donor fragment penetration; therefore, they were a "worst case" test condition.

Test Arrangements

General

During each test phase, the general test array consisted of a centrally located donor and two acceptors, one on each side of the donor (fig. 5). The specimens, either pallets or single submunitions, were raised above the surrounding terrain to simulate the average height of an assembly line off the loading building floor. This configuration produced two sets of acceptor test data results for each donor detonation initiated. The separation distances between the donor and acceptor specimens were varied during both exploratory and individual tests. However, this distance was held constant throughout the entire series of confirmatory tests.

Due to the scarcity of submunitions, the pallet tests were conducted with only the donor pallets having a full complement of 16 submunitions per tray. The acceptor pallets (fig. 5) had loaded submunitions only on the side facing the donor, and the acceptance criteria were modified so that if any one of a set of four acceptors detonted, it counted as if the whole pallet detonated (actually a more severe criterion than originally planned).

Initial Test Program

The initial attack plan for establishing the minimum nonpropagation distance between pallets called for the determination of the free air (unbarricaded) spacing between pallets (fig. 5). A series of four exploratory tests were conducted at separation distances, pallet edge to pallet edge, ranging from a minimum of 0.93 m (3.0 ft) to a maximum of 6.15 m (20.0 ft). Since the apparently safe separation distance (never statistically confirmed) was in excess of what KAAP personnel could economically use on their proposed LAP line layout, testing was suspended pending a review of the line layouts and the existing data.

Revised Test Program

After a series of conferences at both ARDC and KAAP, the test plan was revised to reflect the following four phases of testing:

Phase 1. Pallets of 16 submunitions separated by a barrier allowing airflow

Phase 2. Pallets of 16 submunitions separated by a solid barrier

Phase 3. Single submunitions separated by a 9.5 cm (3.75 in.) high barrier

Phase 4. Single submunitions separated by a full height barrier

The original barriers in Phase 1 were a series of screens made from number 7 mesh stainless steel wire belting, 20.5 cm (8.0 in.) in height, spaced at 30.5 cm (1.0 ft) intervals between donor and acceptor pallets (fig. 6). A series of three exploratory tests were conducted with pallet spacing a maximum distance of 1.54 m (5.0 ft) and four screen barriers between donor and acceptor pallets. Since the 1.54 m spacing was the maximum acceptable by KAAP, the barrier design was revised (figs. 7 and 8). The revision consisted of 1.3 cm (0.5 in.) thick 6061-T6 aluminum plate cut into an open "picket fence" design, with one-layer spaces covered by the next layer's columns either welded or bolted to a base plate. Again, two exploratory tests were conducted with donor-to-acceptor pallet distances ranging from a minimum of 0.61 m (2.0 ft) to a maximum of 1.54 m, with a single picket fence barrier located exactly halfway between the donor and acceptor pallets. This was followed by a series of 25 confirmatory tests using the same test array as in the final exploratory series, with the pallet edge-to-edge distances held constant to compile the necessary statistical data.

In Phase 2, the barriers consisted of 1.3 cm (0.5 in.) thick 6061-T6 aluminum plates, 20.5 cm (8.0 in.) high, and 41.0 cm (16.0 in.) wide, to fully shadow the donor's fragments from the acceptor pallets. A series of three exploratory tests were conducted using the test formats shown in figure 9 and separation distances from 61 cm (24 in.) to 122 cm (48. in.). The barriers (fig. 9), where more than one was used, were spaced on 30.5 cm (12 in.) centers, equally spaced between the donor and acceptor pallets. This was followed by a series of 25 confirmatory tests using a single aluminum barrier with the pallet edge-to-edge distances held constant to compile the necessary statistical data.

Phase 3 consisted of single unit BLU-97/B submunitions separated by an aluminum (6061-T6) barrier, 15.2 cm (6.0 in.) wide by 9.5 cm (3.75 in.) high, with the upper 3.1 cm (1.25 in.) of the body exposed. This configuration simulates positions on a loading machine where tooling requirments preclude complete shielding of the submunition body. A series of four exploratory tests were conducted where variations in barrier thickness, both 1.90 cm (0.75 in.) and 2.54 cm (1.0 in) thick aluminum, and submunition spacing, touching to 23.0 cm (9.0 in.) centerline distance, were used. A confirmatory test phase was then initiated, consisting of 25 tests using identical barriers and the submunition centerline distance held constant in order to compile the necessary statistical data.

Phase 4 consisted of single unit BLU-97/B submunitions separated by an aluminum (6061-T6) barrier with a full height of 15.2 cm (6.0 in.) and width of 15.2 cm to fully shield the submunition's body. A series of four exploratory tests were conducted where variations in barrier thickness and submunitions spacing (similar to Phase 3) were used. A confirmatory phase, while originally planned, was not conduct d.

Method of Initiation

In all cases, the basic donor submunitions were primed with a 15-gram booster charge of Composition C4 explosive and initiated with an engineer's special J2 blasting cap. Due to the layout of the pallet (four groupings of four submunitions), the inner four submunitions were each primed with the 15-gram C4 charge and initiated by the J2 blasting cap (fig. 10). Also, to insure the total donor functioning to a high order detonation, a witness plate was placed under the donor pallet and scrutinized after each test.

TEST RESULTS

Free Air Pallet

Minimum unbarricaded, free air spacing between donor and acceptor pallets (table 1) was determined to be 5.4 m (17.5 ft). Since the safe separation distance was never statistically confirmed, it was not a valid nonpropagation distance for use on future LAP layouts.

Pretest views of the free air pallet test array of tests 1 and 3 of table 1 are shown in figures 11 and 12, respectively. The outboard sandbags were emplaced to aid in acceptor recovery, and in all cases both donor and acceptor pallets had witness plates under them for post test analysis. A post test view of a free air pallet test with the left four being from the left acceptor, etc. is shown in figure 13 (note the fragmentation damage and the one low order detonation).

Pallets with Airflow Barrier

The initial series of pallet tests involved airflow barriers constructed from stainless steel mesh belting. Only three exploratory tests were conducted (section A of table 2, fig. 6) before the maximum acceptable separation distance (as per KAAP) of 1.54 m (5.0 ft) was reached without acceptable results. The test array is shown in figure 14 (test 2 of table 2A) with figures 15 and 16 showing some of the post-test acceptors (note the penetrations of both submunitions and barrier screen). This type of barrier testing was suspended, pending redesign of the barrier. The revised barrier, the picket fence design, went through a series of four exploratory tests in which the pallet spacings were varied from 0.61 m (2.0 ft) to a maximum of 1.54 m (table 2). While there were no high order propagations of donor detonations to acceptor pallets authenticated during the post test examinations, there was an overly sufficient amount of acceptor submunition damage (fragment penetrations and composition burning) at distances to and including 1.22 m (4.0 ft) to indicate an excellent potential for future detonation propagations. Therefore, a distance of 1.54 m was established as the spacing for the confirmatory tests with a single picket fence barrier located halfway between the donor and acceptor pallets. Thus, a series of 25 confirmatory tests were conducted, representing a total of 50 data points at the established conditions to statistically validate the nonpropagation spacing. A view of the typical test array with the airflow picket fence barrier is shown in figure 17, and a view of the test results is shown in figure 18. Note that the airflow barrier was sheared from its base plate by the donor detonation.

Pallets with Solid Barrier

The second series of pallet tests involved the use of solid aluminum barriers 1.3 cm (0.5 in.) thick, 20.5 cm (8.0 in.) high, and 41.0 cm (16.0 in.) wide, which fully protected the acceptors from donor fragments. The exploratory test series consisted of three tests (table 3, tests 1 through 3, respectively). While there were no high order propagations of donor detonations to acceptor pallets, post test examinations indicated sufficient amounts of acceptor damage (fragment penetrations and/or composition burning) at the 61 cm (24 in.) distance to indicate an excellent potential for future propagation. Therefore, for the conduction of the confirmatory test series, a distance of 122 cm (48 in.) was established as the spacing between donor and acceptor pallets with the solid barrier located midway between them. A series of 25 confirmatory tests were then conducted, yielding a total of 50 data points, without a single propagation of a

donor detonation to an acceptor pallet, to statistically validate the nonpropagation spacing. A view of one of the test arrays is shown in figure 19, and a typical post test view is shown in figure 20. In these particular test results, both the left and right shields had many penetrations; some of the left acceptors were crushed by the impact with the shield.

Single Submunitions with Partial Barrier

The third series of tests involved single submunitions separated by aluminum barriers 15.2 cm (6.0 in.) wide by 9.5 cm (3.75 in.) high, with the upper 3.1 cm (1.25 in.) of the submunition exposed. The exploratory test series consisted of four firings (table 4, tests 1 through 4, respectively). The test data showed that the zero separation distances for both thicknesses of barriers resulted in the donor detonation propagation to the acceptors as low order detonations; therefore, unacceptable to meet the test criteria. The conditions of a 2.54 cm (1.0 in.) thick aluminum barrier combined with a 12.8 cm (5.0 in.) centerline spacing on the submunitions was initially established for tentative use in the confirmatory test series; however, a high order detonation propagated to both acceptors (table 4, test 17). The confirmatory test was restarted using a submunition centerline spacing of 22.9 cm (9.0 in.). This distance, with the 2.54 cm thick aluminum barrier, was statistically confirmed by the successful conduction of 25 confirmatory tests yielding 50 data points. A view of a typical test setup showing the barriers only shielding the lower 75% of the submunitions is shown in figure 21. A post test view of a similar test array showing (1) the witness plate with only the donor hole, (2) both acceptors partially crushed from barrier impact, and (3) the barriers themselves chopped up by donor fragment impacts, is shown in figure 22.

Single Submunition with Full Barrier

The fourth and final test series involved single submunitions separated by aluminum barriers 15.2 cm (6.0 in.) square which shielded the submunition to its full height (fig. 23). As in Phase 3, a series of exploratory tests were conducted (table 5) resulting in the establishment of the conditions of a 2.54 cm (1.0 in.) thick barrier combined with a 12.8 cm (5.0 in.) centerline spacing between submunitions for the follow-on confirmatory test series. However, since these are the exact same conditions as established and statistically confirmed in the Phase 3 testing, its confirmatory test data, being a worst-case condition, will be used for both Phases 3 and 4.

Analysis of Test Results

Variations in manufacturing tolerances, materials, wear, etc. require that statistical reasoning be employed in the interpretation of the confirmatory data from each test phase. The actual probability of a continuous propagation of an unexpected explosive incident on a LAP line is a function of the number of propa-

gation occurrences in a particular test portion as related to the total number of test detonations conducted (app).

In Phase 1, a total of 51 observation data points were recorded using a single picket fence barrier placed halfway between the donor and acceptor pallets, which were spaced 1.54 m (5.0 ft) apart, edge-to-edge distance. This resulted in an upper limit of 7.0% probability of propagation of an explosive incident at the 95% confidence level.

In Phase 2, a total of 52 observations were recorded using a single 1.3 cm (5.0 in.) thick barrier placed halfway between the donor and acceptor pallets, which were spaced 1.22 m (4.0 ft) apart, edge-to-edge distance. This resulted in an upper limit of 6.8% probability of propagation of an explosive incident at the 95% confidence level.

Phases 3 and 4 were conducted as one test series. A total of 52 observations were recorded using the worst case, or partial barriers, and the centerline separation distance of 22.9 cm (9.0 in.) resulted in an upper limit of 6.8 probability of propagation of an explosive incident at the 95% confidence level.

These values are equivalent to stating that, in a large number of tests (95 out of 100 times), the probability of an unexpected explosive incident propagating to a catastrophic event will be less than, or equal to, the values previously stated (table 6). These values indicate the quality of the test results and the reliance that can be placed upon the conclusions drawn from the data.

CONCLUSIONS

1. Pallets containing 16 submunitions and using the picket fence airflow barrier spaced 1.54 m (5.0 ft) apart, edge-to-edge, have a 7% probability of the propagation of an explosive incident at a confidence level of 95%.

2. Pallets containing 16 submunitions and using a solid barrier 1.3 cm (0.5 in.) thick, spaced 1.22 m (4.0 ft) apart, edge-to-edge, have a 6.8% probability of the propagation of an explosive incident at a confidence level of 95%.

3. Single submunitions using a 2.5 cm (1.0 in.) thick barrier, 9.5 cm (3.75 in.) high [upper 3.1 cm (1.25 in.) of the submunition exposed] spaced on a 22.9 cm (9.0 in.) centerline distance, have a 6.8% probability of the propagation of an explosive incident at a confidence level of 95%.

4. Single submunitions using a 2.5 cm (1.0 in.) thick barrier, 15.2 cm (6.0 in.) high to fully shield the submunitions body, spaced 22.9 cm (9.0 in.) centerline distance apart, have a 6.8% probability of the propagation of an explosive incident at a confidence level of 95%.

In all four configurations, the barrier was considered to be the full width of the conveyor belt. Also, all barriers were constructed of 6065-T6 aluminum.

RECOMMENDATIONS

Based upon the test results, it is recommended that the conclusions of this report should be considered in the design, acceptance, and operation of the LAP facilities for the BLU-97/B submunitions.

Table 1. Pallet tests without barrier

Test	Separation distance m	(ft)	Acceptor results
1L	1.22	4.0	Severe damage to all submunitions, one burned, one ruptured, all had multiple penetrations
1R	0.91	3.0	Declared a nontest since only left half of donor functioned properly
2L	3.66	12.0	Submunitions sustained severe damage, one ruptured, manv penetrations
2R	1.83	6.0	One with several penetrations, one complete burn, and all others with penetrations and severe damage
3L	6.10	20.0	Submunitions had several hits but no penetrations
3R	4.57	15.0	One submunition had one penetration, no burning, but several hits
4L	6.10	20.0	Several hits but no penetrations
4R	5.33	17.5	Several hits but no penetrations

Table 2. Pallet tests with airflow barrier

A. Mesh Screen Tests

Test 1--Single barrier had 24-inch pallet spacing and one barrier. Both left and right test arrays were the same setup. After donor detonation, all four left acceptors were recovered; however, one had functioned with a low order detonation. Only two of the right acceptors were recovered with many hits and penetrations, and the witness plate indicated that the other two functioned with high order detonations.

Test 2--Left side had two barriers and a 36-inch spacing; the right side had three barriers and a 48-inch pallet spacing. After the donor detonation, there were no propagations to either side. However, sufficient penetrations of submunitions on both sides of the acceptors were noted, including one burnout of composition on the left side to indicate an excellent potential for future detonation propagations.

Test 3--Both sides used a four-barrier array with 60-inch spacing. This spacing was the maximum acceptable to the facility layout. After donor detonation, there was no propagation to the acceptors on either side; however, as in test 2, there were sufficient penetrations to indicate an excellent potential for future detonation propagations.

B. Picket Fence Tests

Test	Separation distance m	Separation distance (ft)	Acceptor results
1L	0.76	2.5	All submunitions hit by fragments, two were fully penetrated and one burned out
1R	1.52	5.0	All submunitions recovered, no hits or penetrations noted
2L	0.61	2.0	Many penetrations of all submunitions with one complete burnout
2R	1.22	4.0	One submunition with penetrations and one burnout
3L	1.52	5.0	No propagations, one penetration
3R	1.52	5.0	No propagatins, three hits, no penetrations
4L	1.52	5.0	No propagations, no hits or penetrations
4R	1.52	5.0	No propagations, no hits or penetrations
5L	1.52	5.0	One penetration and three hits
5R	1.52	5.0	Minor hits only

Table 2. (cont)

Test	Separation distance m	(ft)	Acceptor results
6L	1.52	5.0	No penetrations, minor hits
6R	1.52	5.0	No penetrations, minor hits
7L	1.52	5.0	No penetrations, minor hits
7R	1.52	5.0	No penetrations, minor hits
8L	1.52	5.0	No penetrations, minor hits
8R	1.52	5.0	No penetrations, minor hits
9L	1.52	5.0	No penetrations, minor hits
9R	1.52	5.0	No penetrations, minor hits
10L	1.52	5.0	No penetrations, minor hits
10R	1.52	5.0	No penetrations, minor hits
11L	1.52	5.0	Nontest, donor tray did not fully function to high order
11R	1.52	5.0	detonation
12L	1.52	5.0	No penetrations, minor hits
12R	1.52	5.0	No penetrations, minor hits
13L	1.52	5.0	No penetrations, minor hits
13R	1.52	5.0	No penetrations, minor hits
14L	1.52	5.0	No penetrations, minor hits
14R	1.52	5.0	No penetrations, minor hits
15L	1.52	5.0	No penetrations, minor hits
15R	1.52	5.0	One penetration and burn, others with minor hits
16L	1.52	5.0	No penetrations, minor hits
16R	1.52	5.0	No penetrations, minor hits
17L	1.52	5.0	No penetrations, minor hits
17R	1.52	5.0	No penetrations, minor hits
18L	1.52	5.0	No penetrations, minor hits
18R	1.52	5.0	No penetrations, minor hits
19L	1.52	5.0	One penetration and explosive scattered, no burn
19R	1.52	5.0	No penetrations, minor hits
20L	1.52	5.0	No penetrations, minor hits
20R	1.52	5.0	No penetrations, minor hits

Table 2. (cont)

Test	Separation distance m	(ft)	Acceptor results
21L	1.52	5.0	No penetrations, minor hits
21R	1.52	5.0	No penetrations, minor hits
22L	1.52	5.0	One penetration with explosive scattered, no burn
22R	1.52	5.0	Two penetrations with explosive scattered, no burns
23L	1.52	5.0	One penetration with explosive scattered, no burn
23R	1.52	5.0	One penetration with explosive scattered, no burn
24L	1.52	5.0	One penetration with explosive scattered, no burn
24R	1.52	5.0	Two penetrations with explosive scattered, no burns
25L	1.52	5.0	No penetrations, minor hits
25R	1.52	5.0	No penetrations, minor hits
26L	1.52	5.0	One low order detonation, no damage to three other units
26R	1.52	5.0	No penetrations, minor hits
27L	1.52	5.0	One penetration with explosive scattered, no burn
27R	1.52	5.0	No penetrations, minor hits
28L	1.52	5.0	One penetration with explosive scattered, no burn
28R	1.52	5.0	One penetration with explosive scattered, no burn

Table 3. Pallet tests with solid barrier

Test	Separation distance m	(ft)	Acceptor results
1L*	1.22	4.0	No propagation or damage
1R	1.22	4.0	No propagation or damage
2L	1.22	4.0	No propagation, few hits
2R	0.61	2.0	Many penetrations and hits
3L	0.61	2.0	Many penetrations, one burnout
3R	0.61	2.0	Many penetrations
4L	1.22	4.0	One penetration, submunitions flattened, no burn
4R	1.22	4.0	No penetrations, submunitions crushed
5L	1.22	4.0	Two penetrations, all crushed, no burn
5R	1.22	4.0	One penetration, all crushed, no burn
6L	1.22	4.0	One penetration, all crushed, no burn
6R	1.22	4.0	No penetrations, all crushed
7L	1.22	4.0	One penetration, all crushed, no burn
7R	1.22	4.0	Two penetrations, one burn, all crushed
8L	1.22	4.0	One penetration with 10% burn, all crushed
8R	1.22	4.0	One penetration with explosive scattered, all crushed, no burn
9L	1.22	4.0	One penetration, all crushed, no burn
9R	1.22	4.0	One penetration, all crushed, no burn
10L	1.22	4.0	No penetrations, all crushed
10R	1.22	4.0	Two penetrations, no burn, all crushed
11L	1.22	4.0	No penetrations, all crushed
11R	1.22	4.0	Two penetrations, all crushed, no burn
12L	1.22	4.0	Two penetrations, all crushed, no burn
12R	1.22	4.0	No penetrations, all crushed, no burn
13L	1.22	4.0	No penetrations, all crushed
13R	1.22	4.0	One penetration, all crushed, no burn

* Had two barriers between donor and acceptor.

Table 3. (cont)

Test	Separation distance m	(ft)	Acceptor results
14L	1.22	4.0	No penetrations, all crushed
14R	1.22	4.0	No penetrations, all crushed
15L	1.22	4.0	No penetrations, all crushed
15R	1.22	4.0	One penetration, all crushed, no burn
16L	1.22	4.0	No penetrations, all crushed
16R	1.22	4.0	No penetrations, all crushed
17L	1.22	4.0	One penetration, all crushed, no burn
17R	1.22	4.0	No penetrations, all crushed
18L	1.22	4.0	One penetration with 100% burn ignited a second acceptor to 100% burn, all crushed, no other burn
18R	1.22	4.0	One penetration, all crushed, no burn
19L	1.22	4.0	No penetrations, no other damage
19R	1.22	4.0	No penetrations, no other damage
20L	1.22	4.0	No penetrations, all crushed
20R	1.22	4.0	Two penetrations, all crushed, no burn
21L	1.22	4.0	Two penetrations, all crushed, no burn
21R	1.22	4.0	One penetration, all crushed, no burn
22L	1.22	4.0	No penetrations, all crushed
22R	1.22	4.0	No penetrations, all crushed
23L	1.22	4.0	One penetration, all crushed, no burn
23R	1.22	4.0	One penetration, all crushed, no burn
24L	1.22	4.0	No penetrations, all crushed
24R	1.22	4.0	No penetrations, all crushed
25L	1.22	4.0	One penetration, all crushed, no burn
25R	1.22	4.0	One penetration, all crushed, no burn
26L	1.22	4.0	No penetrations, all crushed
26R	1.22	4.0	No penetrations, all crushed
27L	1.22	4.0	No penetrations, all crushed
27R	1.22	4.0	No penetrations, all crushed
28L	1.22	4.0	No penetrations, all crushed
28R	1.22	4.0	No penetrations, all crushed

Table 4. Single submunition test with partial height barrier

Test	Separation distance m	Separation distance (ft)	Acceptor results
1L*	0	0	Acceptor detonated
1R*	0	0	Acceptor detonated
2L	0	0	Acceptor detonated
2R	0	0	Acceptor detonated
3L	12.7	5.0	No penetrations, acceptor crushed
3R	22.9	9.0	No penetrations, acceptor crushed
4L	12.7	5.0	No penetrations, acceptor crushed
4R	22.9	9.0	No penetrations, acceptor crushed
5L	12.7	5.0	Acceptor crushed, explosive scattered, no burn
5R	12.7	5.0	Acceptor crushed, explosive burned
6L	12.7	5.0	One penetration, acceptor crushed, no burn
6R	12.7	5.0	One penetration, acceptor crushed, no burn
7L	12.7	5.0	One penetration, acceptor crushed, no burn
7R	12.7	5.0	One penetration, acceptor crushed, no burn
8L	12.7	5.0	No penetration, acceptor split open, no burn
8R	12.7	5.0	No penetration, acceptor split open, no burn
9L	12.7	5.0	One penetration, acceptor split open, no burn
9R	12.7	5.0	One penetration, acceptor split open, 20% burn
10L	12.7	5.0	Two penetrations, acceptor split open, no burn
10R	12.7	5.0	Three penetrations, acceptor split open, no burn
11L	12.7	5.0	Three penetrations, acceptor crushed, 20% burn
11R	12.7	5.0	Three penetrations, acceptor split open, no burn
12L	12.7	5.0	No penetration, acceptor split open, no burn
12R	12.7	5.0	No penetration, acceptor crushed, 100% burn
13L	12.7	5.0	No penetration, acceptor split open, no burn
13R	12.7	5.0	Two penetrations, acceptor split open, no burn
14L	12.7	5.0	One penetration, acceptor split open, no burn
14R	12.7	5.0	One penetration, acceptor split open, no burn

* This test used a 0.75-in. thick shield, all others used a 1.0-in. thick shield.

Table 4. (cont)

Test	Separation distance m	(ft)	Acceptor results
15L	12.7	5.0	Three penetrations, acceptor crushed, 100% burn
15R	12.7	5.0	Two penetrations, acceptor crushed, no burn
16L	12.7	5.0	No penetration, acceptor crushed, no burn
16R	12.7	5.0	No penetration, acceptor crushed, no burn
17L	12.7	5.0	High order detonation of acceptor
17R	12.7	5.0	High order detonation of acceptor
18L	22.9	9.0	One penetration, acceptor crushed, no burn
18R	22.9	9.0	One penetration, acceptor crushed, 100% burn
19L	22.9	9.0	No penetration, acceptor crushed, no burn
19R	22.9	9.0	One penetration, acceptor crushed, 100% burn
20L	22.9	9.0	No penetration, acceptor crushed, no burn
20R	22.9	9.0	One penetration, acceptor crushed, no burn
21L	22.9	9.0	No penetration, acceptor crushed, no burn
21R	22.9	9.0	One penetration, acceptor crushed, no burn
22L	22.9	9.0	Two penetrations, acceptor crushed, 100% burn
22R	22.9	9.0	One penetration, acceptor crushed, no burn
23L	22.9	9.0	One penetration, acceptor crushed, no burn
23R	22.9	9.0	Two penetrations, acceptor crushed, 100% burn
24L	22.9	9.0	One penetration, acceptor crushed, no burn
24R	22.9	9.0	One penetration, acceptor crushed, no burn
25L	22.9	9.0	One penetration, acceptor crushed, no burn
25R	22.9	9.0	Two penetrations, acceptor crushed, no burn
26L	22.9	9.0	One penetration, acceptor crushed, no burn
26R	22.9	9.0	One penetration, acceptor crushed, no burn
27L	22.9	9.0	One penetration, acceptor crushed, no burn
27R	22.9	9.0	Two penetration, acceptor crushed, no burn
28L	22.9	9.0	One penetration, acceptor crushed, no burn
28R	22.9	9.0	No penetration, acceptor crushed, no burn
29L	22.9	9.0	One penetration followed by low order detonation
29R	22.9	9.0	One penetration, acceptor crushed, no burn

Table 4. (cont)

Test	Separation distance m	(ft)	Acceptor results
30L	22.9	9.0	Two penetrations, acceptor crushed, 100% burn
30R	22.9	9.0	Two penetrations, acceptor crushed, no burn
31L	22.9	9.0	No penetration, acceptor crushed, no burn
31R	22.9	9.0	No penetration, acceptor crushed, 100% burn
32L	22.9	9.0	One penetration, acceptor crushed, no burn
32R	22.9	9.0	One penetration, acceptor crushed, no burn
33L	22.9	9.0	No penetration, acceptor crushed, no burn
33R	22.9	9.0	Two penetrations, acceptor crushed, no burn
34L	22.9	9.0	No penetration, acceptor split open, no burn
34R	22.9	9.0	One penetration, acceptor crushed, no burn
35L	22.9	9.0	One penetration, acceptor crushed, no burn
35R	22.9	9.0	Three penetrations, acceptor crushed, no burn
36L	22.9	9.0	Two penetrations, acceptor split open, no burn
36R	22.9	9.0	Low order detonation of acceptor
37L	22.9	9.0	One penetration, acceptor crushed, no burn
37R	22.9	9.0	One penetration, acceptor crushed, no burn
38L	22.9	9.0	One penetration, acceptor crushed, no burn
38R	22.9	9.0	Two penetrations, acceptor crushed, no burn
39L	22.9	9.0	One penetration, acceptor crushed, no burn
39R	22.9	9.0	One penetration, acceptor crushed, no burn
40L	22.9	9.0	One penetration, acceptor crushed, no burn
40R	22.9	9.0	One penetration, acceptor crushed, no burn
41L	22.9	9.0	One penetration, acceptor crushed, no burn
41R	22.9	9.0	One penetration, acceptor crushed, no burn
42L	22.9	9.0	No penetration, acceptor crushed, no burn
42R	22.9	9.0	Low order detonation of acceptor

Table 5. Single submunition tests with full height barrier*

Test	Barrier thickness cm	Barrier thickness (in.)	Separation distance cm	Separation distance (in.)	Acceptor results
1L	1.88	0.75	0	0	Low order detonation
1R	1.88	0.75	0	0	Low order detonation
2L	2.54	1.00	0	0	Low order detonation
2R	2.54	1.00	0	0	Low order detonation
3L	2.54	1.00	12.8	5.0	No propagation, acceptor damaged
3R	2.54	1.00	23.0	9.0	No propagation, no damage
4L	2.54	1.00	12.8	5.0	No propagation, minor damage
4R	2.54	1.00	12.8	5.0	No propagatin, acceptor crushed

* The full height barrier testing was discontinued after completion of the exploratory phase. Since the barrier thickness and separation distance established was the same as for the partial height barriers, its confirmatory phase test data, as a more severe or worse case condition, will be considered as valid for both test conditions.

Table 6. Summary of results

Configuration	Number of tests	Separation cm	Separation (in.)	Probability (%)
Pallet with airflow barrier	51	154.0	60.0	7.0
Pallet with solid barrier	52	122.0	48.0	6.8
Single submunition with partial barrier	52	22.9	9.0	6.8
Single submunition with full barrier	52	22.9	9.0	6.8

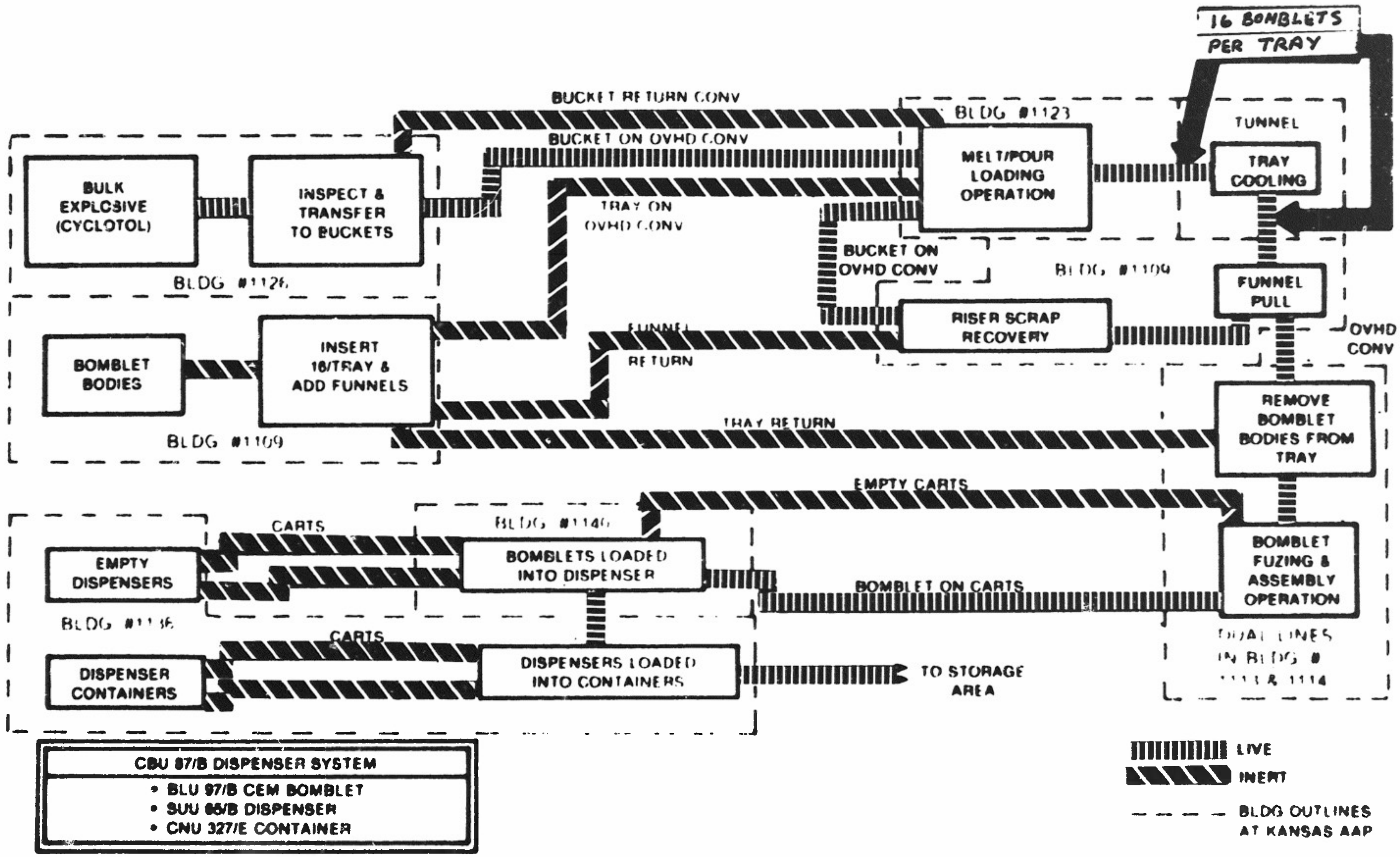

Figure 1. Production flow

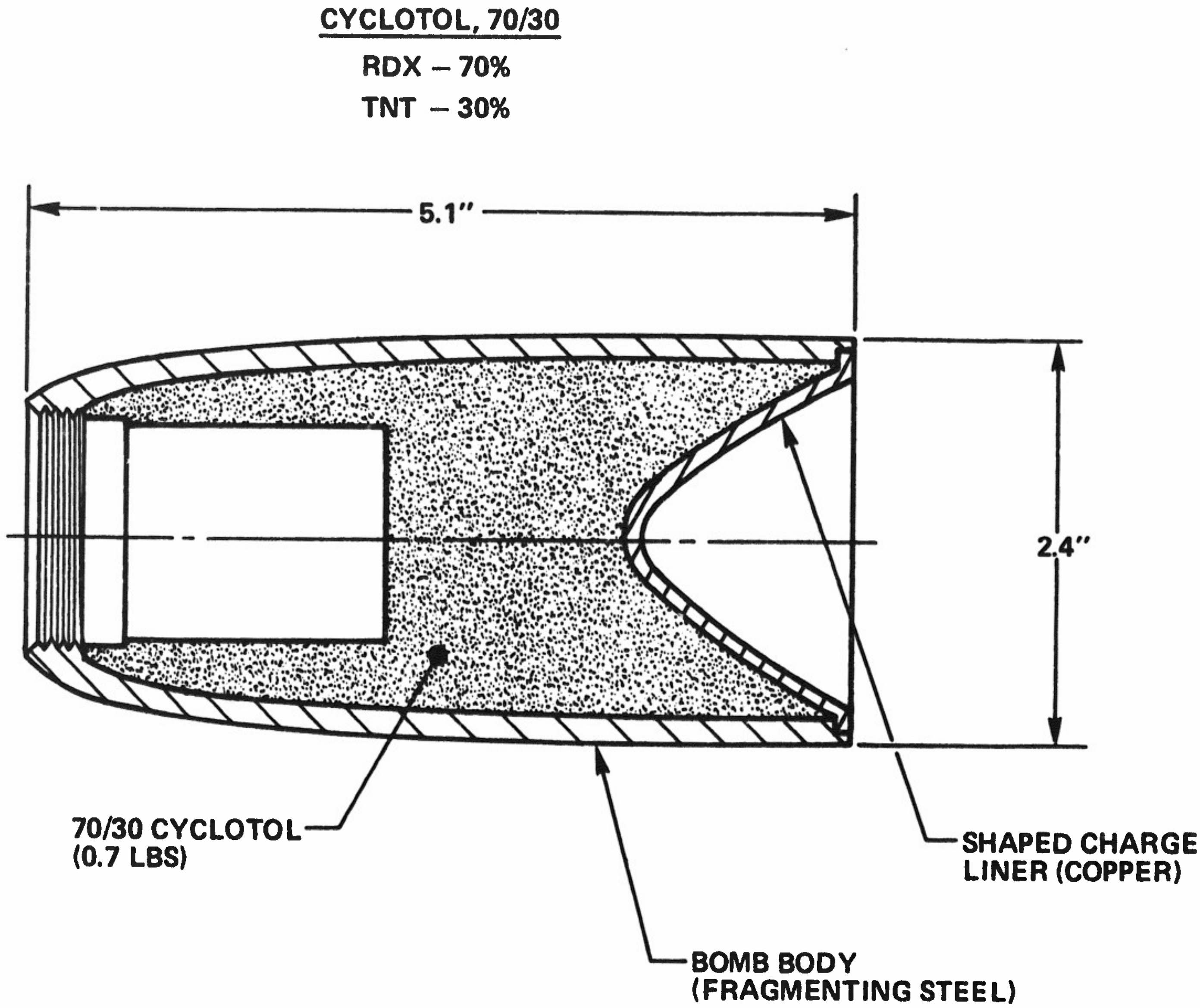

Figure 2. Combined effects submunition loaded body assembly

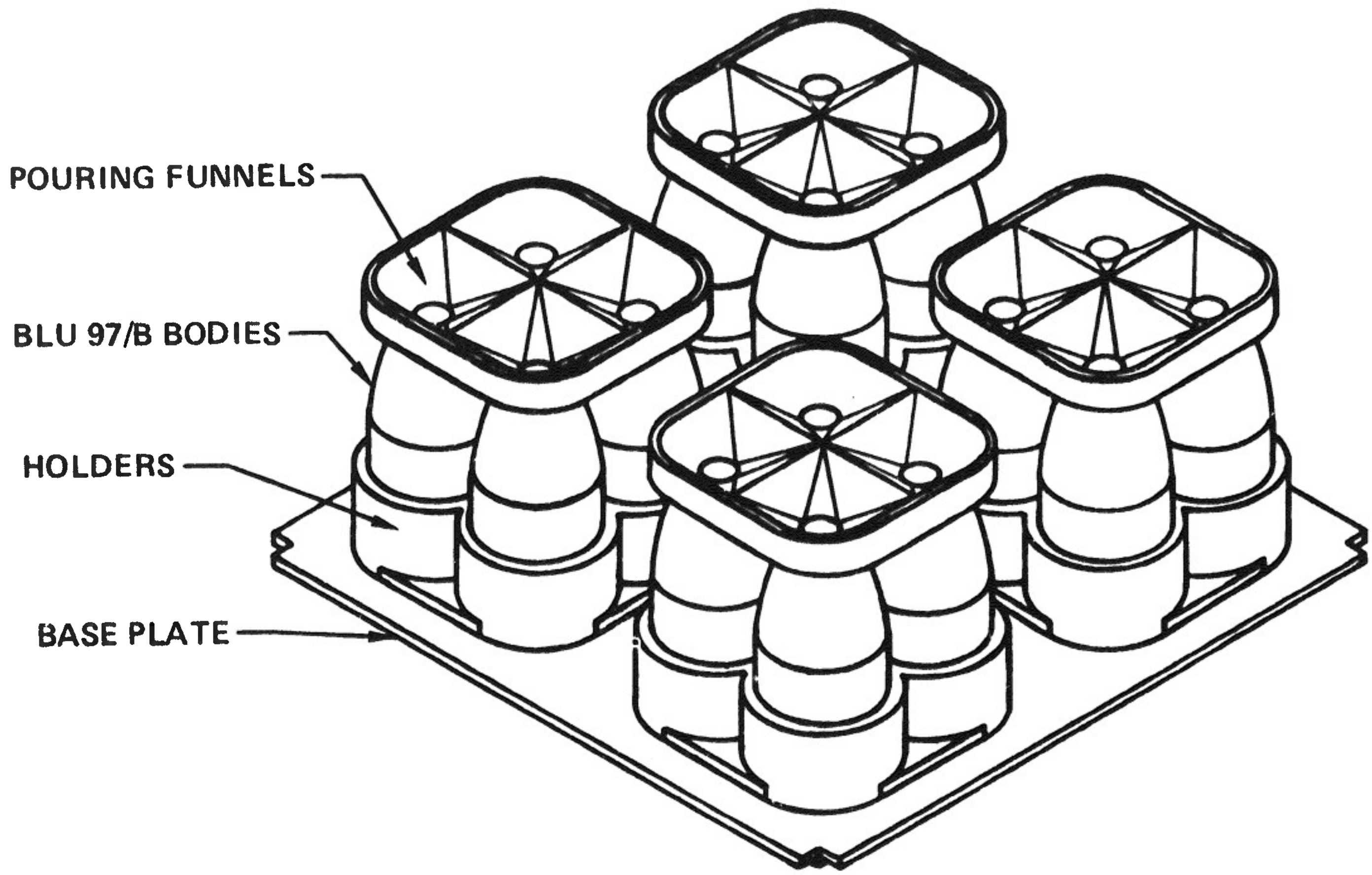

Figure 3. CEM pouring tray assembly

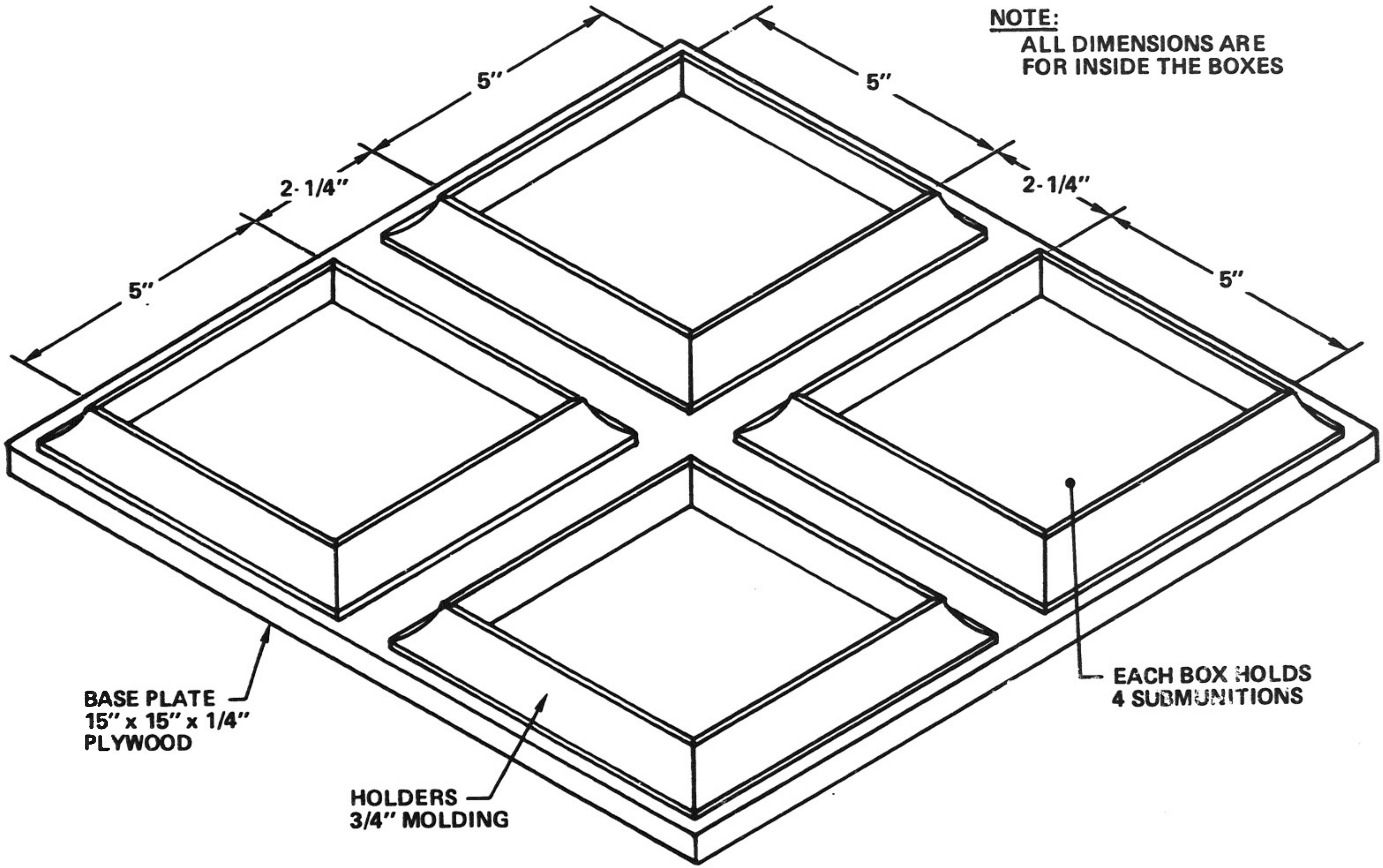

Figure 4. Simulated 16 unit array pouring tray

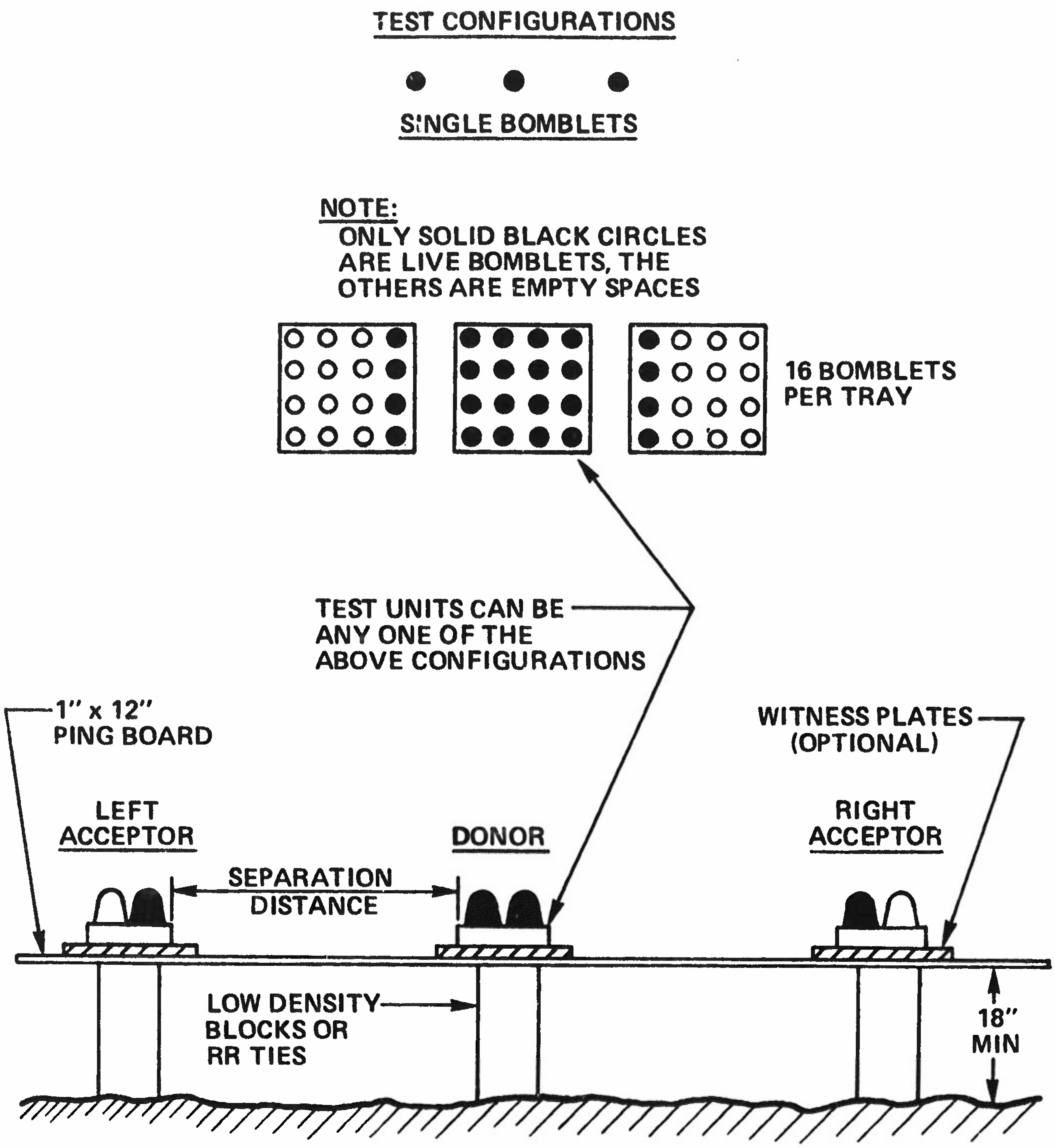

Figure 5. Combined effects submunition nonpropagation test array

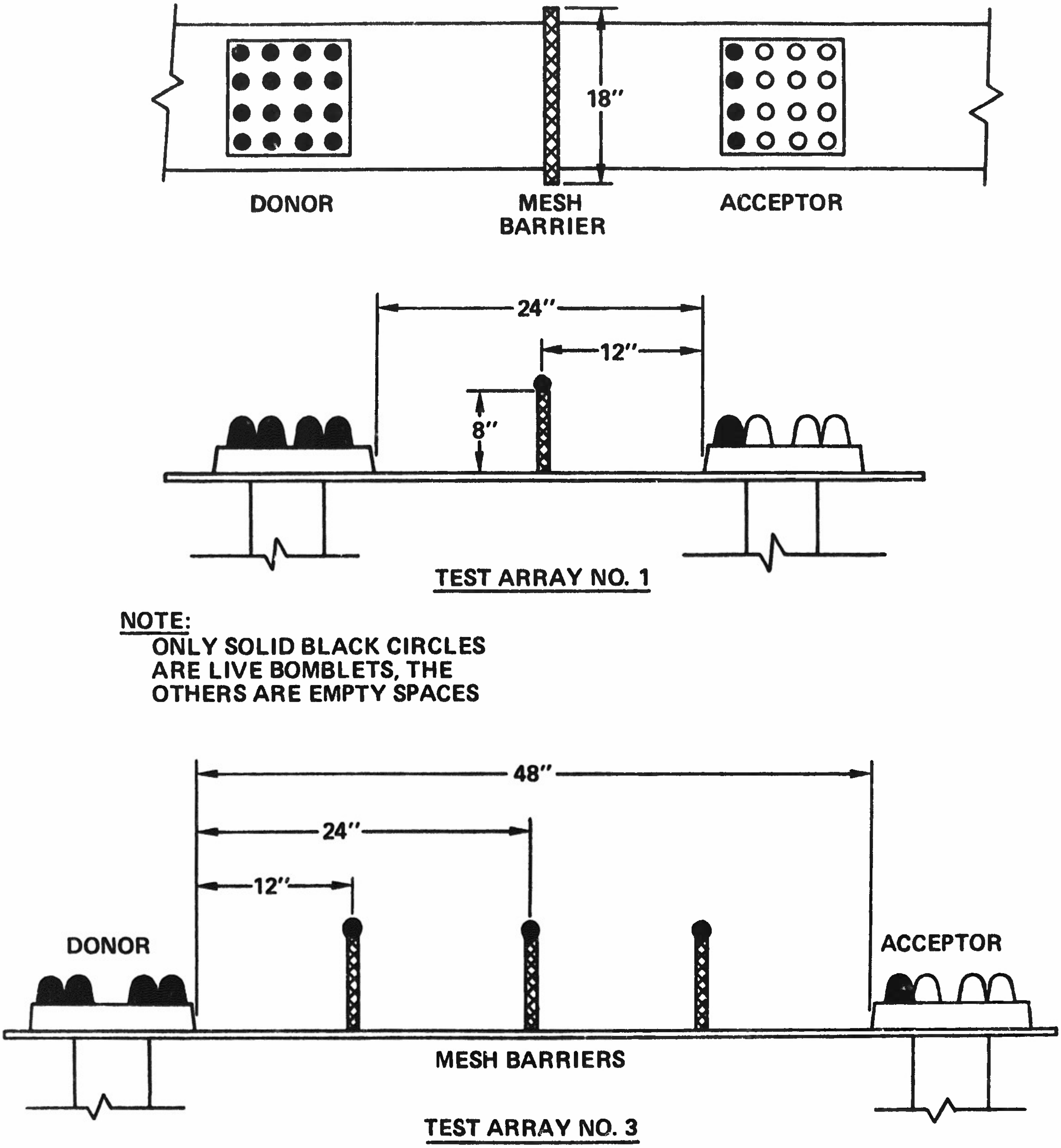

Figure 6. Airflow (mesh) barrier test array

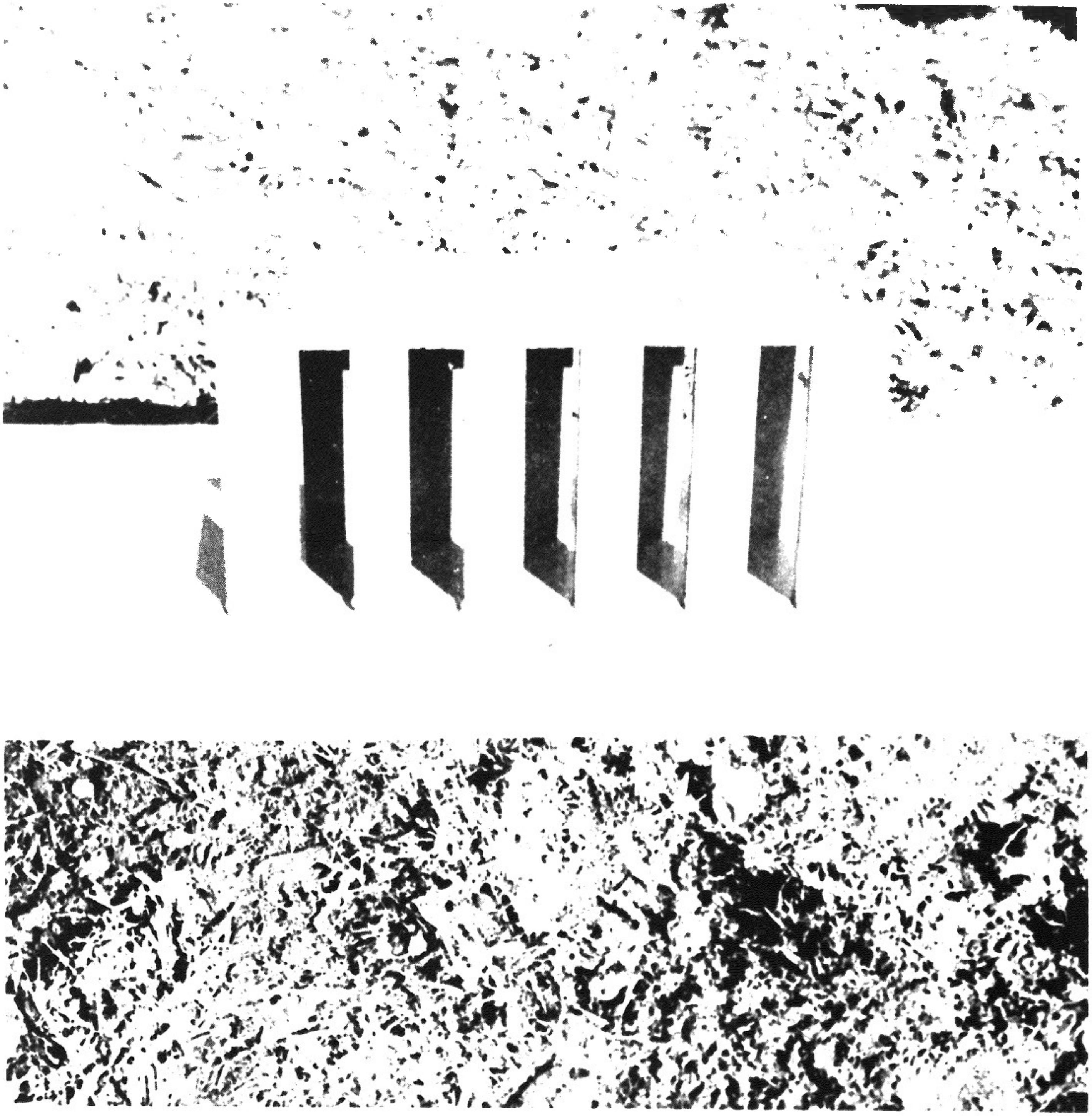

Figure 7. Airflow picket fence barrier, front view

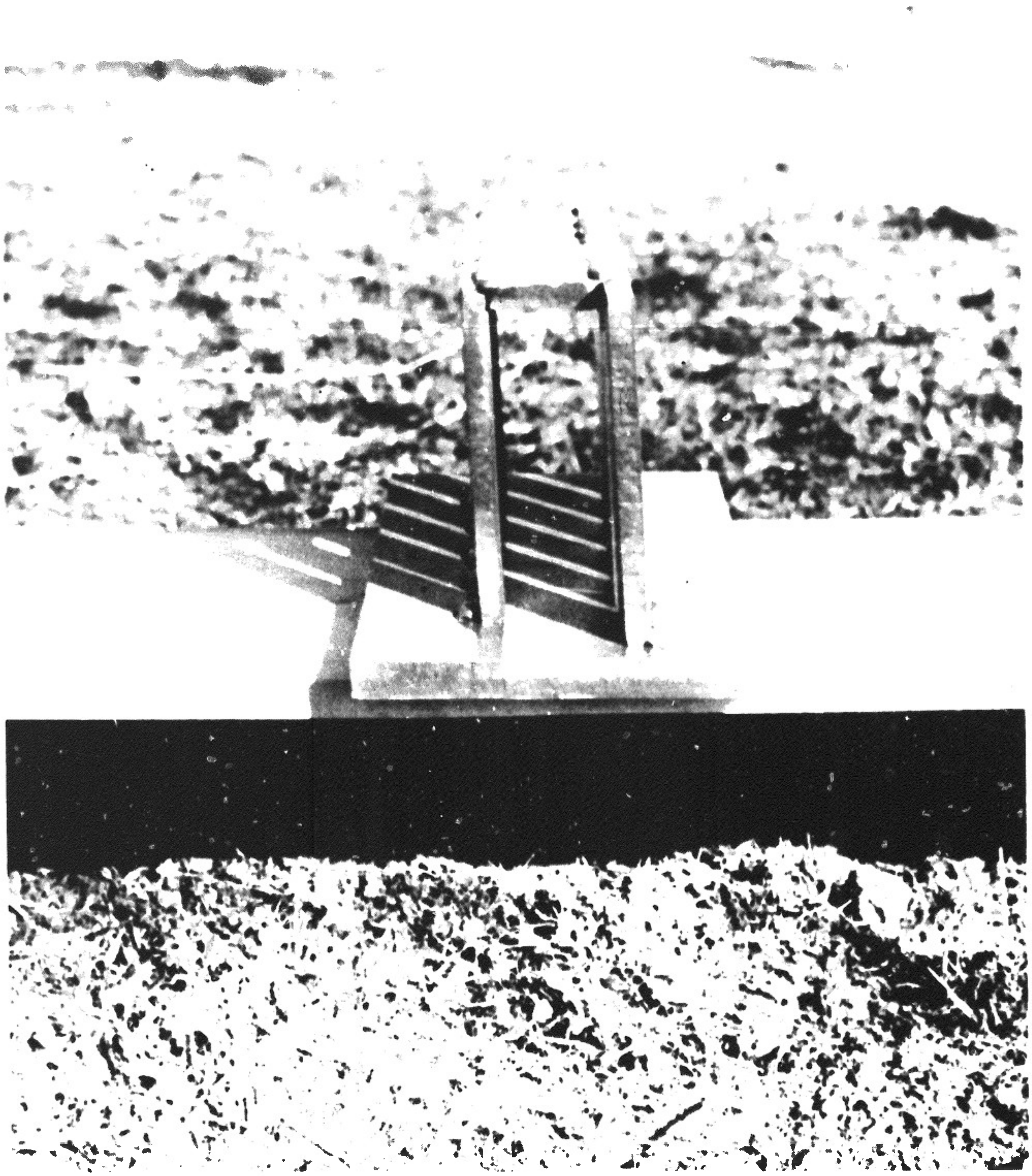

Figure 8. Airflow picket fence barrier, side view

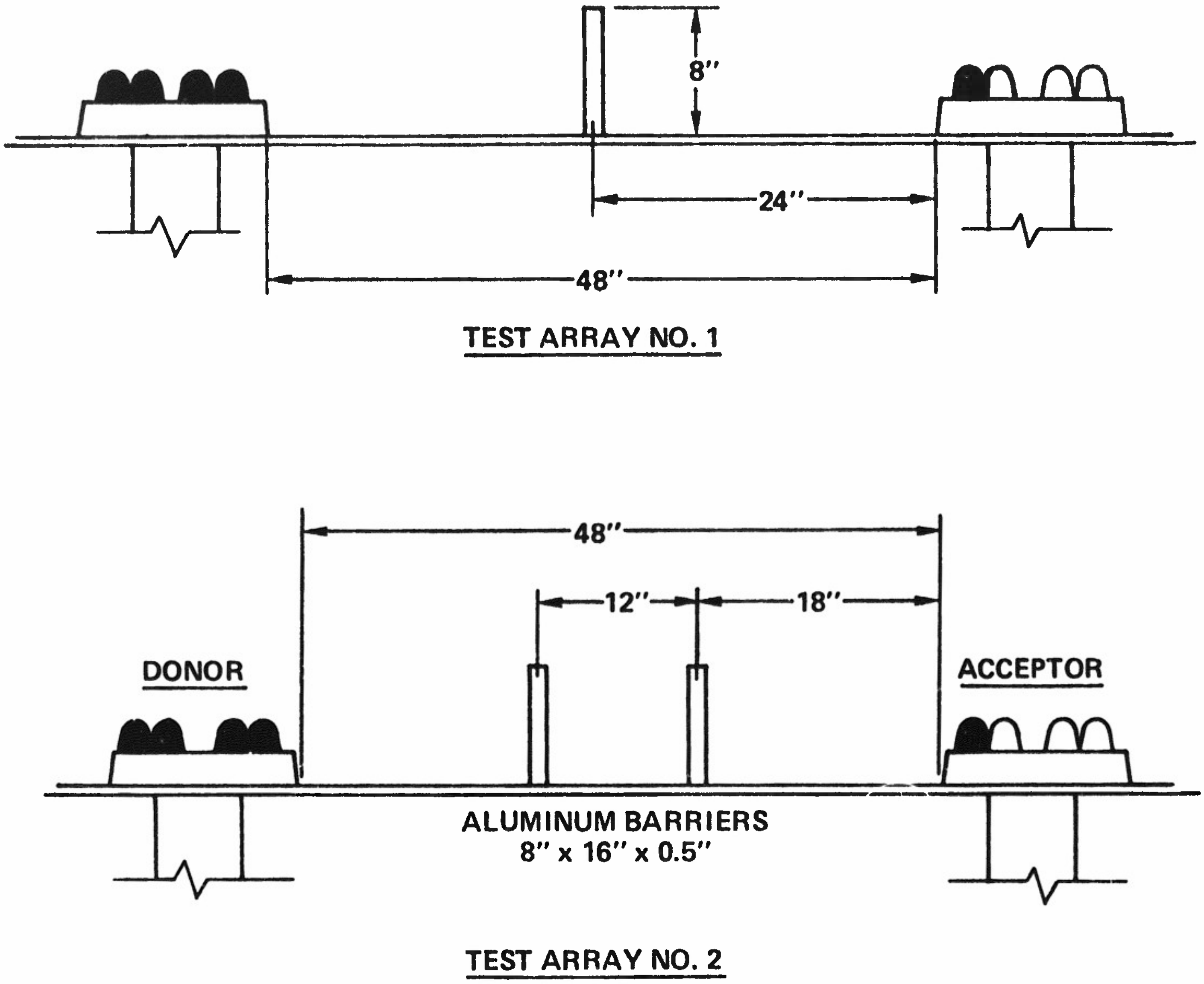

Figure 9. Solid barrier test array

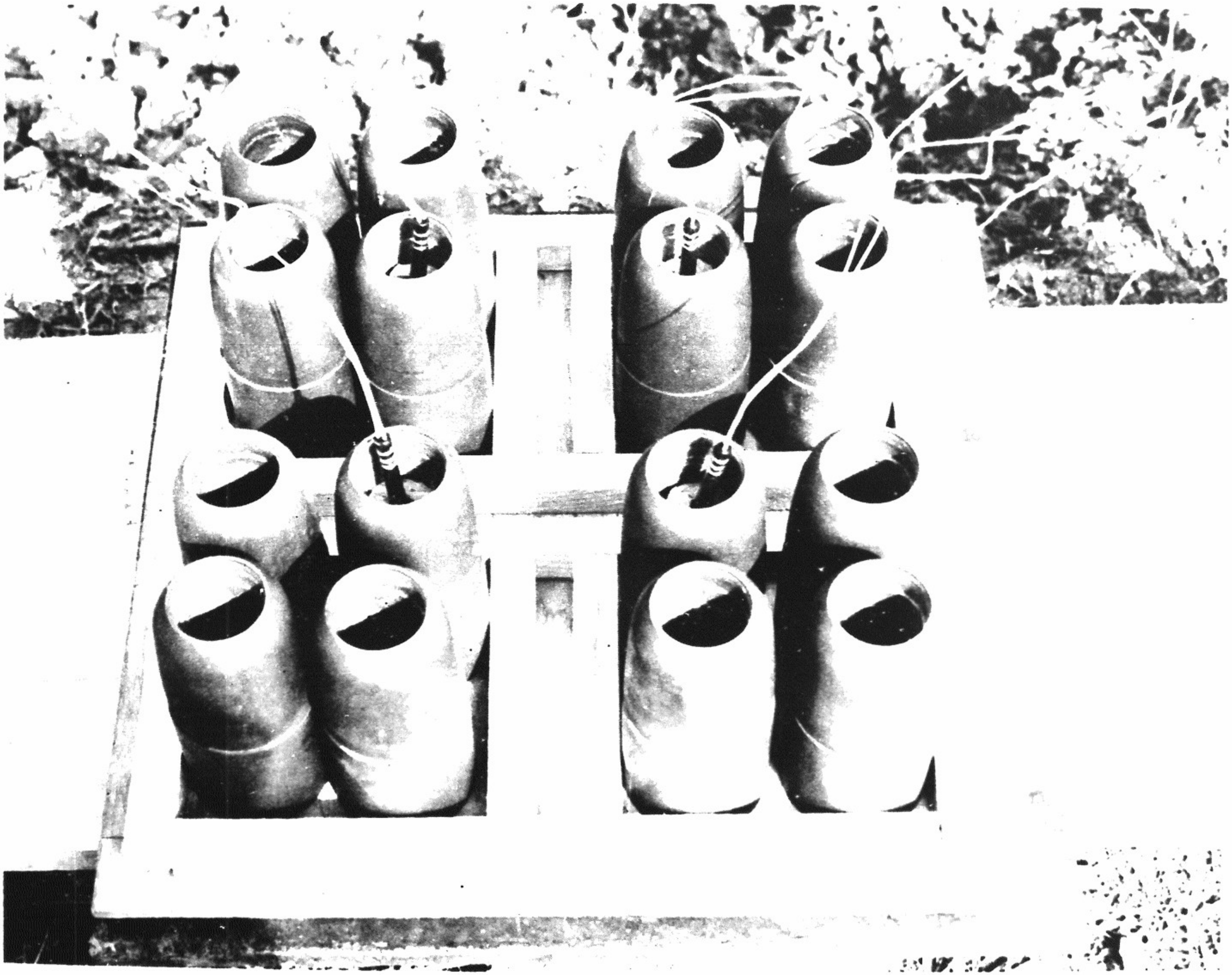

Figure 10. Pallet of 16 primer array

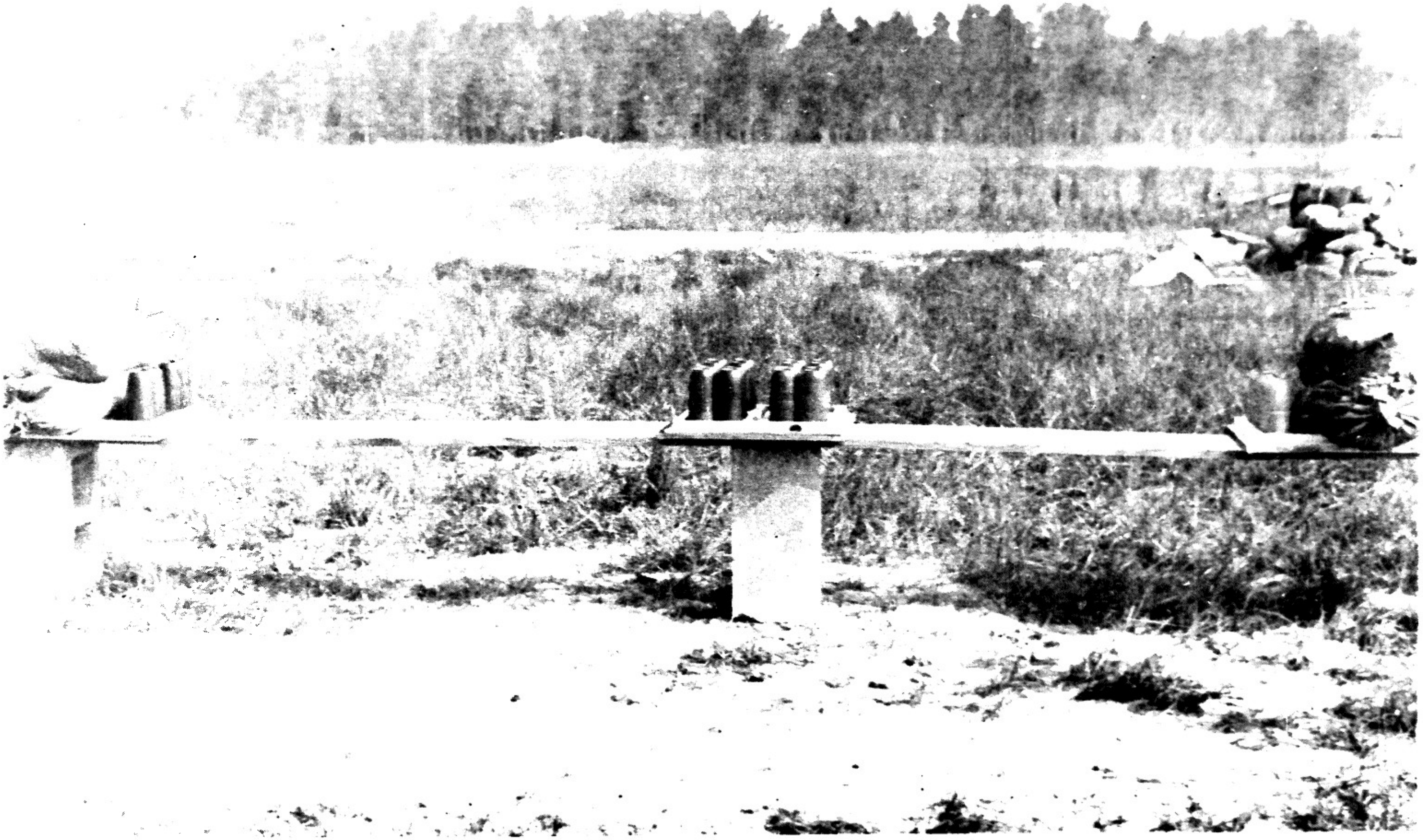

Figure 11. Pretest view of free air pallet test 1

Figure 12. Pretest view of free air pallet test 3

Figure 13. Free air pallet test results

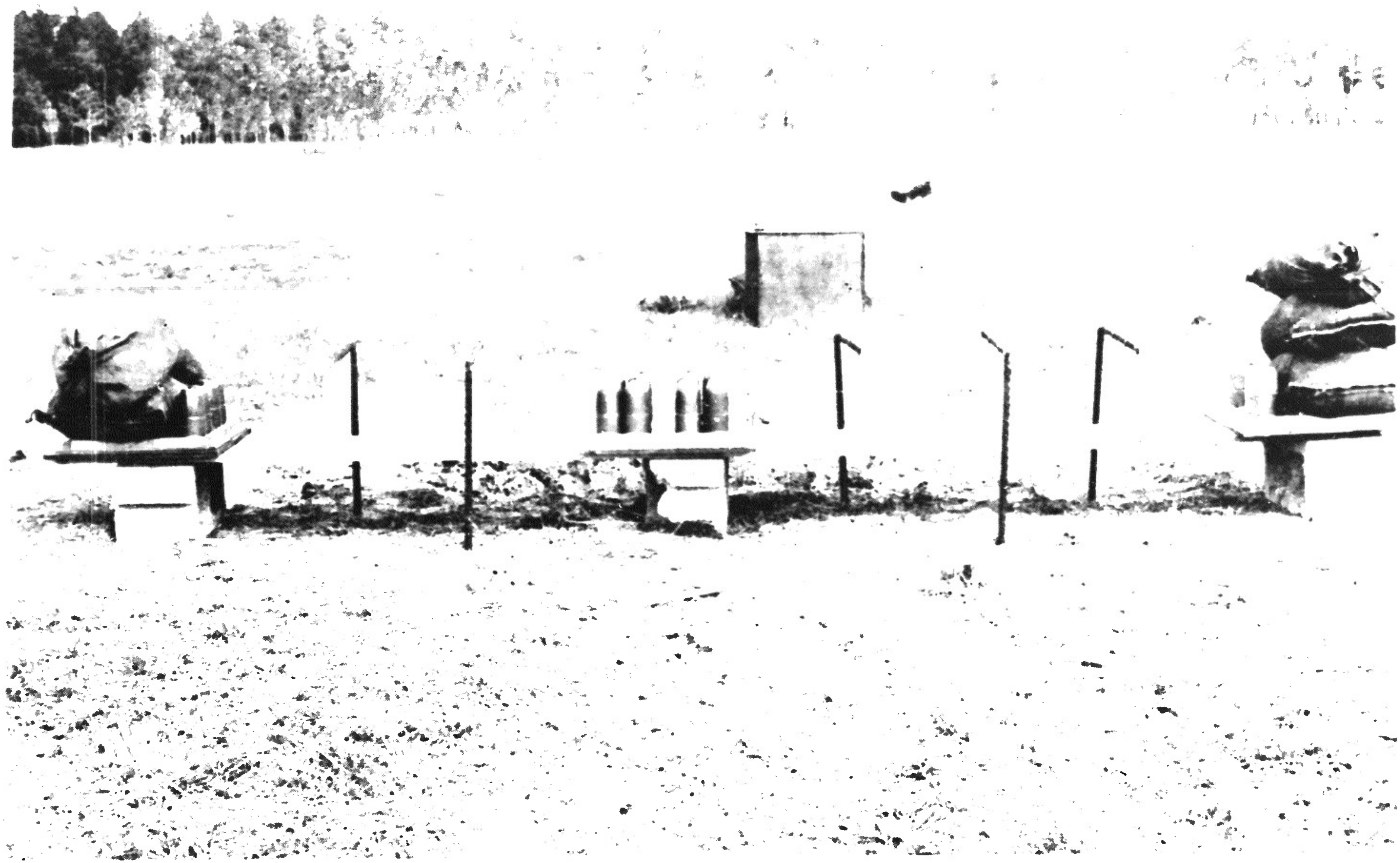

Figure 14. Airflow mesh barrier array

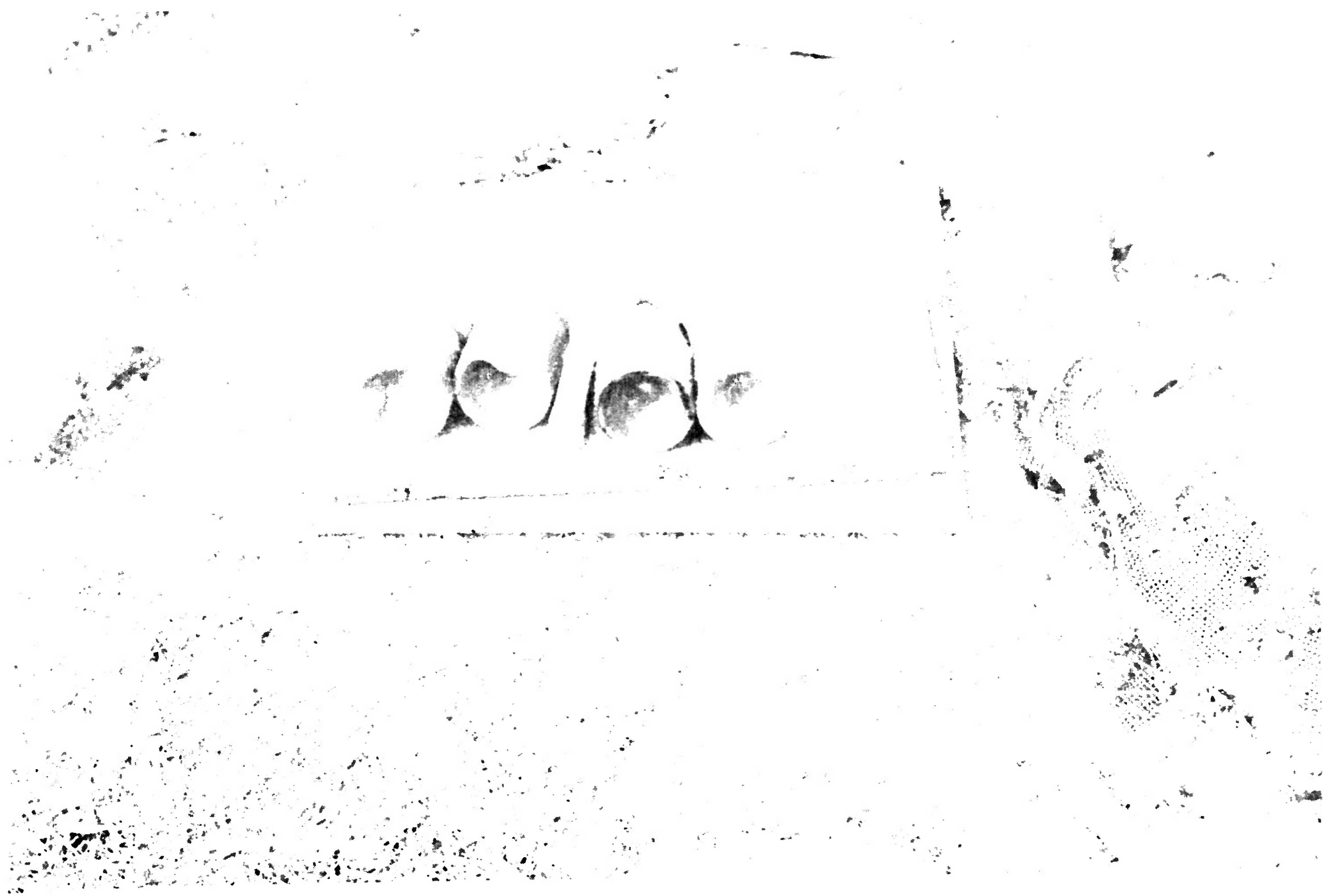

Figure 15. Airflow mesh barrier test results, right acceptor

Figure 16. Airflow mesh barrier test results, left acceptor

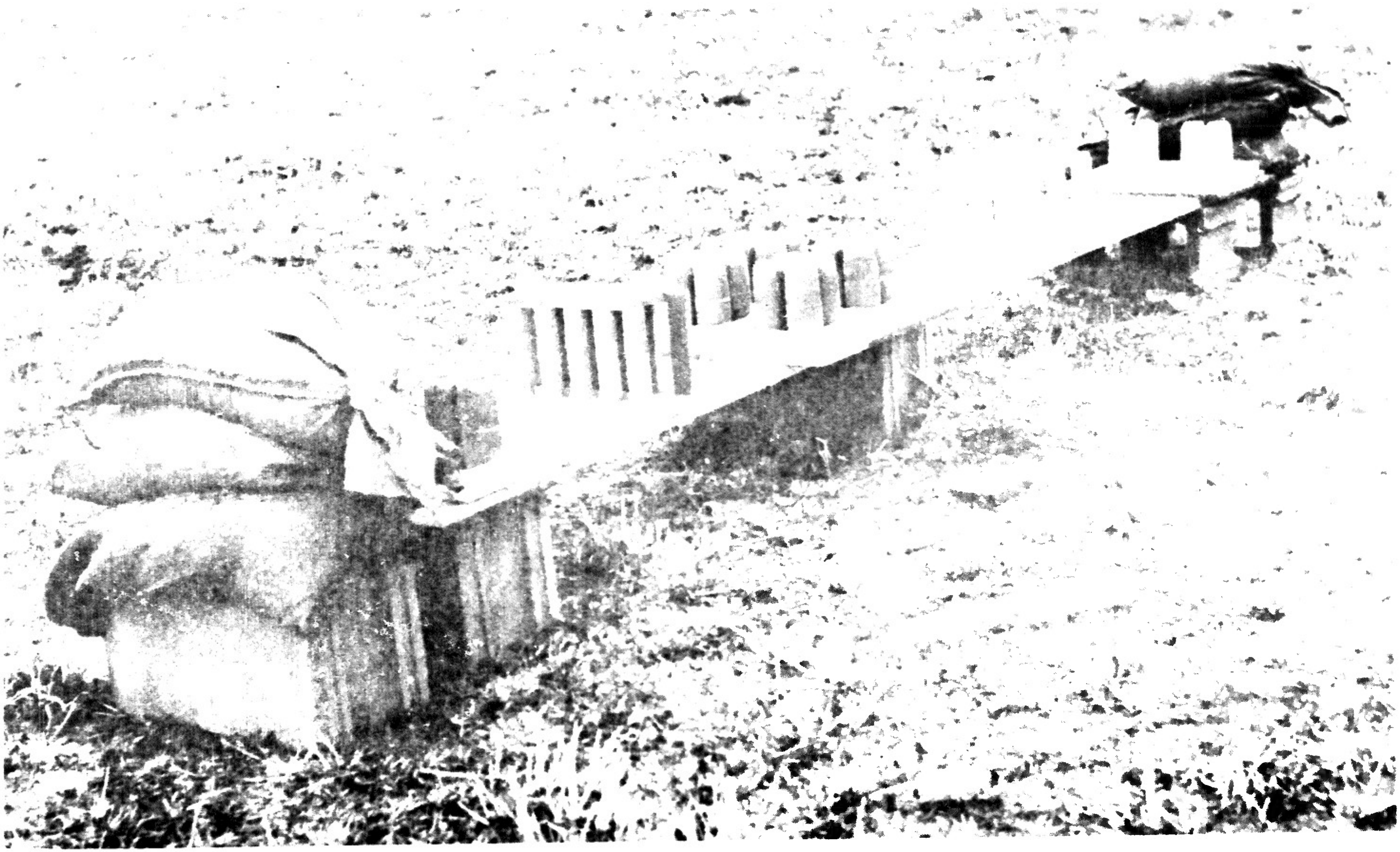

Figure 17. Airflow picket fence test array

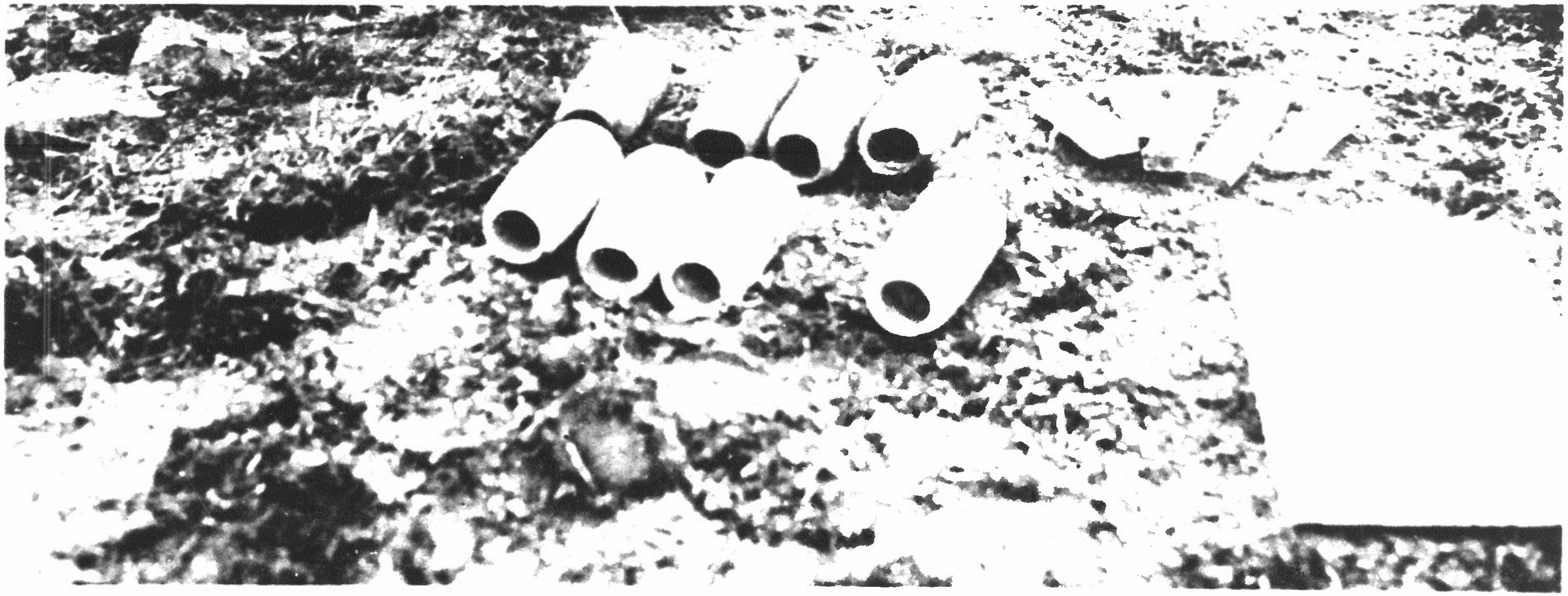

Figure 18. Airflow picket fence barrier test results

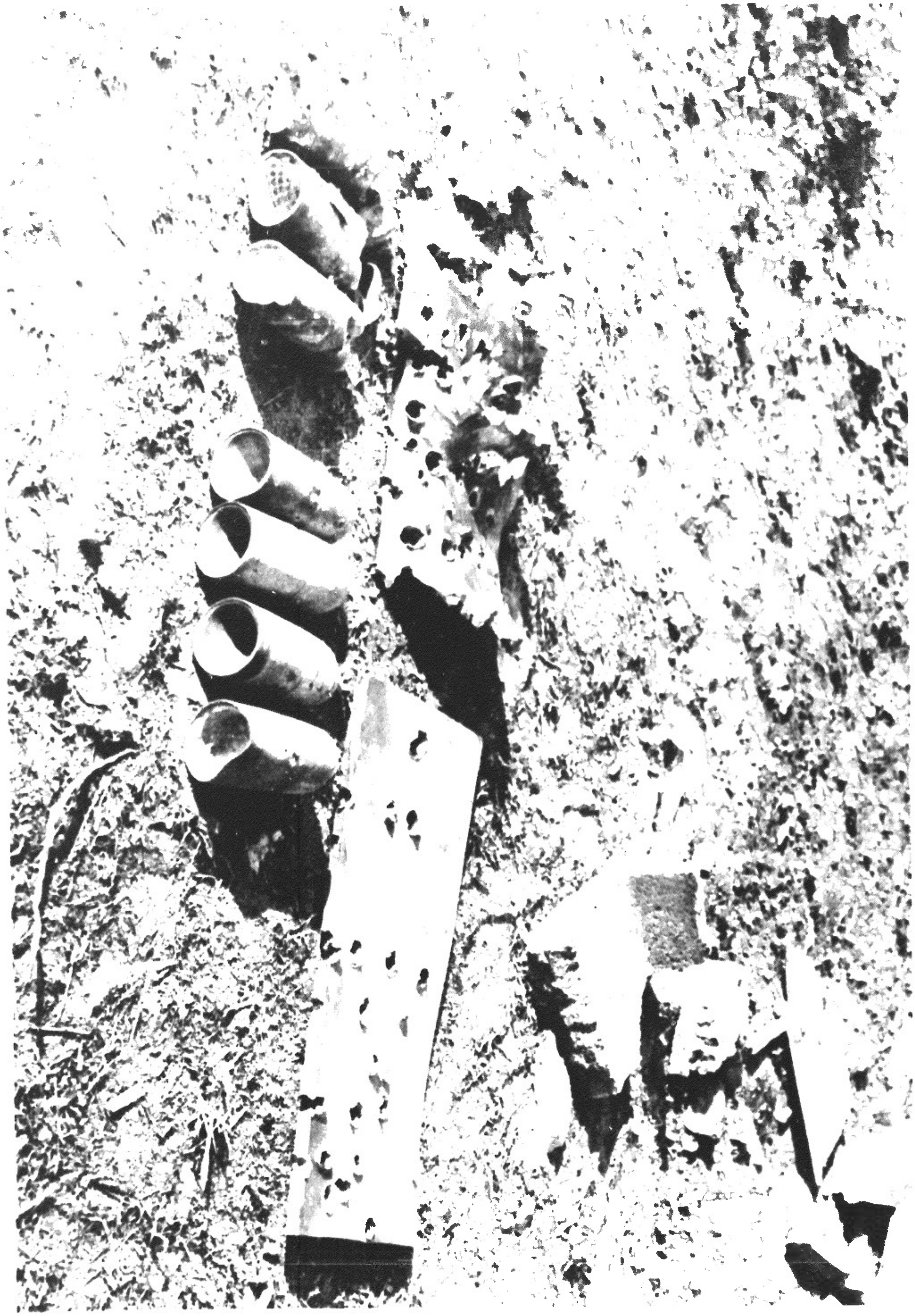

Figure 20. Solid barrier test results

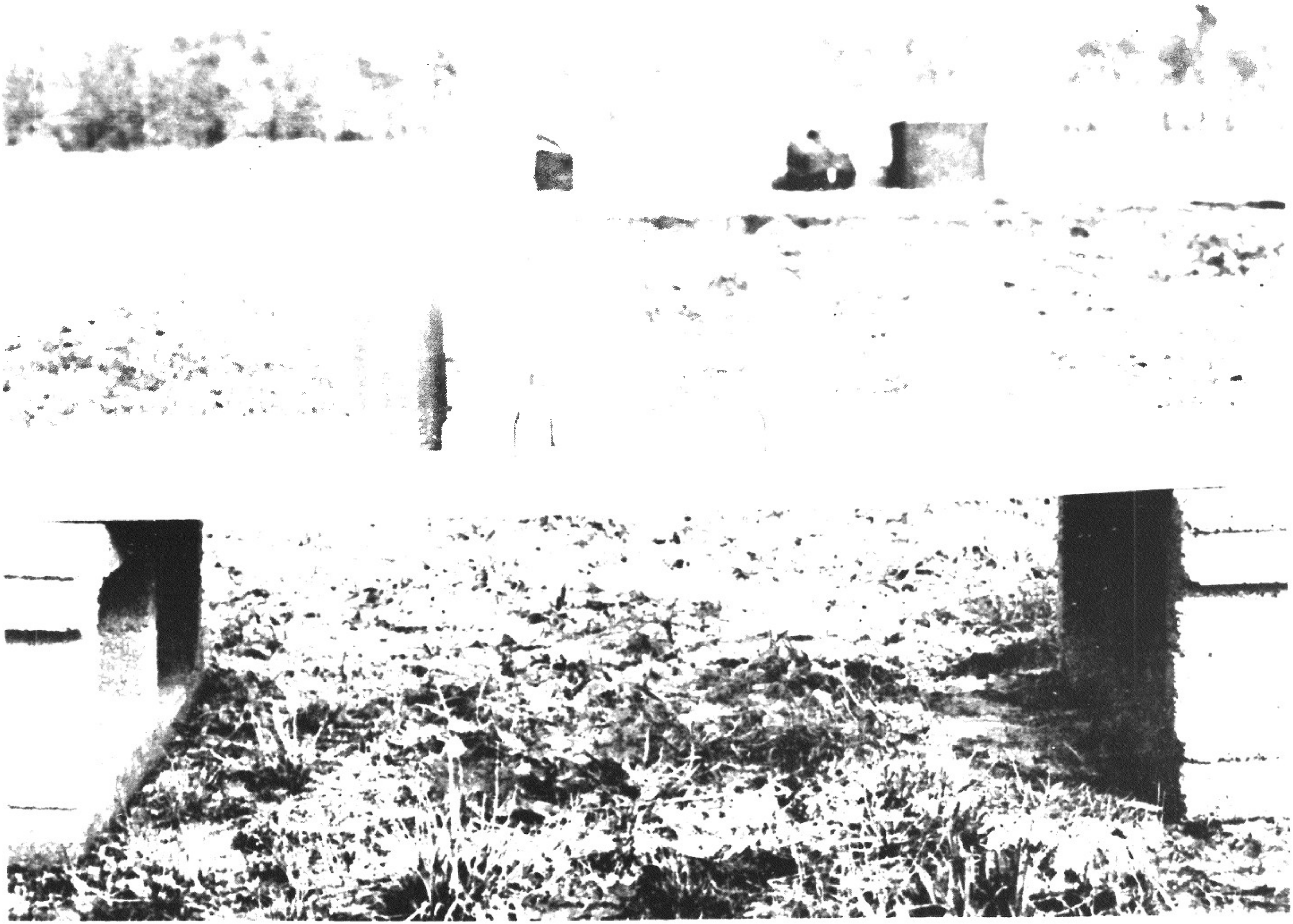

Figure 21. Single submunition with partial barrier test array

Figure 22. Test results of single submunition with partial barrier

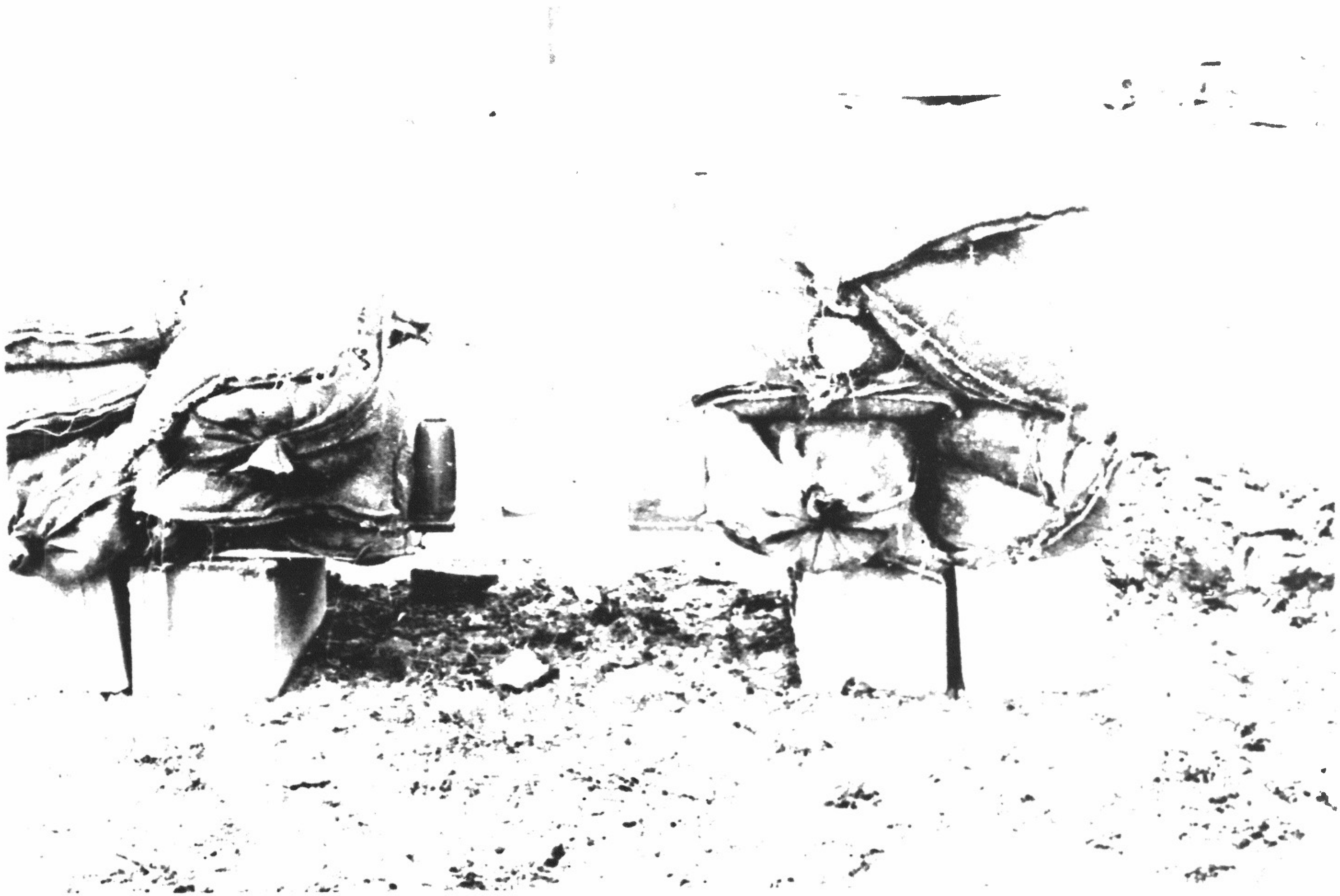

Figure 23. Single submunition with full barrier test array

APPENDIX

STATISTICAL EVALUATION OF EXPLOSION PROPAGATION

The possibility of the occurrence of explosion propagation based upon a statistical analysis of the test results has been evaluated in the main body of the report. This appendix is devoted to the mathematical means by which the statistical analysis was performed.

The probability of the occurrence of an explosion propagation is dependent upon the degree of certainty or confidence level involved and has upper and lower limits. The lower limit for all confidence levels is zero; whereas, the upper limit is a function of the number of observations or, in this particular case, the number of acceptor items tested. Since each observation is independent of the others and each observation has a constant probability of a reaction occurrence (explosion propagation), the number of reactions (x) in a given number of observations (n) will have a binomial distribution. Therefore, the estimate of the probability (p) of a reaction occurrence can be represented mathematically by

$$p = x/n \tag{1}$$

and, therefore, the expected value of x is given by

$$E(x) = np \tag{2}$$

Each confidence level will have a specific upper limit (p_2) depending upon the number of observations involved. The upper probability limit for a given confidence level α, when a reaction is not observed, is expressed as

$$(1 - p_2)^n = \varepsilon \tag{3}$$

where

$$\varepsilon = (1 - \alpha)/2 \text{ and } \alpha < 1.0 \tag{4}$$

Use of equation 3 is illustrated in the following example:

Example: Determine the upper probability limit of the occurrence of an explosion propagation for a confidence level of 95% based upon 30 observations without a reaction occurrence.

Given: Number of observations (n) = 30
Confidence level (α) = 95%

Solution: 1. Substitute the given value of (α) into equation 4 and solve for ε

$$\varepsilon = (1 - \alpha)/2 = (1 - 0.95)/2 = 0.025$$

2. Substitute the given value of n and value of ε into equation 3 and solve for p_2

$$\varepsilon = 0.025 = (1 - p_2)^{30}$$

or

$$p_2 = 0.116 \ (11.6\%)$$

Conclusions: For a 95% confidence level and 30 observations, the true value of the probability of explosion propagation will fall between zero and 0.116, or statistically, it can be interpreted that in 30 observations, a maximum of (0.116 x 30) = 3.48 observations could result in a reaction for a 95% confidence level.

Probability Table

The probability limits and the range of the expected value E(x) for different numbers of observations are shown in table A-1. Three confidence limits, 90, 95, and 99%, are used to derive the probabilities. The same values are plotted in figure A-1.

Table A-1. Probabilities of propagation for various confidence limits (C.L.)

Number of observations n	90% p_2	C.L. / E(x)	95% p_2	C.L. / E(x)	99% p_2	C.L. / E(x)
10	0.259	2.59	0.308	3.08	0.411	4.11
20	0.131	2.62	0.168	3.36	0.233	4.66
30	0.095	2.85	0.116	3.48	0.162	4.86
40	0.072	2.88	0.088	3.52	0.124	4.96
50	0.058	2.9	0.071	3.55	0.101	5.05
60	0.049	2.92	0.060	3.6	0.085	5.10
80	0.037	2.96	0.045	3.6	0.064	5.12
100	0.030	3.0	0.036	3.6	0.052	5.2
200	0.015	3.0	0.018	3.6	0.026	5.2
300	0.010	3.0	0.012	3.6	0.018	5.4
500	0.006	3.0	0.007	3.5	0.011	5.5

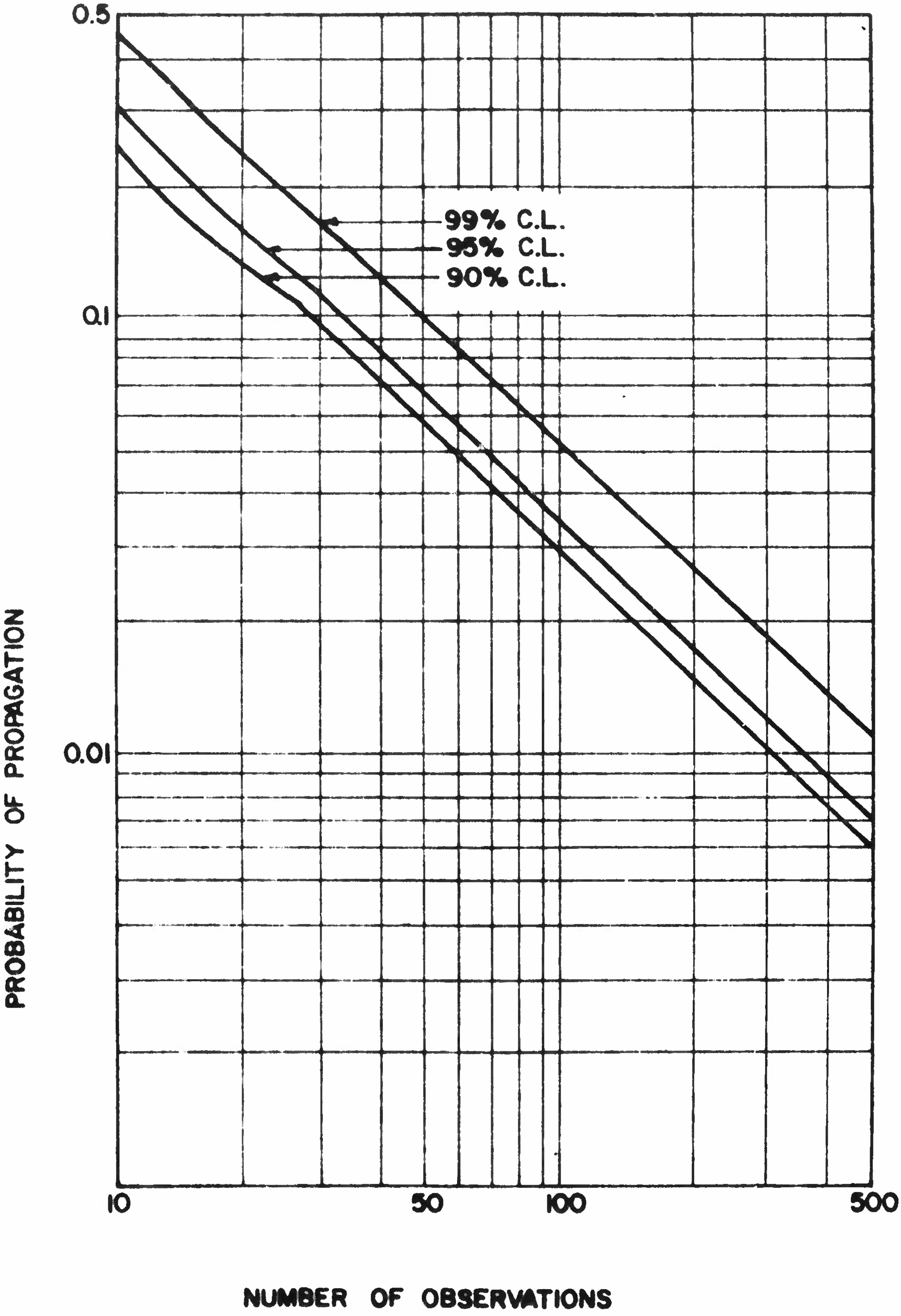

Figure A-1. Variations of propagation probability versus number of observations as a function of confidence level

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